TITLE
What are the effects of blood flow restriction exercise and high load resistance exercise on the muscle activation patterns, oxygenation and metabolic responses in endurance and strength trained athletes?

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What are the effects of blood flow restriction exercise and high load resistance exercise on the muscle activation patterns, oxygenation and metabolic responses in endurance and strength trained athletes?

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Abstract

In recent years the literature surrounding blood flow restriction (BFR) exercise has begun to focus on the physiological responses of strength and endurance trained athletes to bouts of BFR training. Research suggests that athletes of different phenotypes respond very differently to BFR exercise (Takada et al., 2012). Therefore, there is an opportunity to discover more about the use of BFR exercise in athletic training and rehabilitation for athletes of different phenotypes. Six endurance runners and seven weightlifters with a mean age of 25.5±4.7 years were recruited. The experiment followed a cross-over design and consisted of two separate back squat protocols: BFR and high load resistance (HLR). Four sets of each of these protocols were performed by both groups. The BFR protocol was performed with blood pressure cuffs attached just below the inguinal crease and utilised 70% Limb Occlusion Pressure (LOP) with 30% one repetition maximum (1RM), with a repetition scheme of 30,15,15,15, while the HLR protocol involved squatting 80% 1RM without BFR to the repetition scheme of 7,7,7,7. These repetition schemes were selected to match the total volume load between the two exercise protocols. Electromyography (peak and % of normalisation), Tissue Saturation Index (TSI), and blood lactate were analysed for both conditions. The HLR condition produced significantly greater neuromuscular activity for all muscles across both groups and the contribution of the vastus lateralis (VL) to the total activity of the movement significantly increased under BFR conditions compared to HLR conditions (47.1±2.7% vs 33.2±2.3% respectively, $p<0.05$). There was a significantly greater mean decrease in TSI from rest under BFR conditions compared to HLR, while the strength group showed significantly greater differences to resting values across both conditions compared to the endurance group (17.0±1.2% vs 12.9±1.3% respectively, $p<0.05$). There was a significant negative correlation ($r=-0.66$, $p<0.05$) between post-exercise blood lactate values and the TSI of the final set of the BFR protocol. There were very few significant

differences between the strength and endurance groups for BFR or HLR exercise, yet the acute metabolic changes observed in the BFR protocol signal the presence of the mechanisms responsible for protein synthesis. Therefore it is suggested that the longitudinal use of this BFR protocol would lead to increases in strength and hypertrophy.

Introduction

Developed in Japan, the physiological benefits of restricting blood flow during exercise were quickly realised and it soon became common practice for physiotherapists to prescribe BFR exercises to injured athletes (Sato, 2005). Furthermore the partnership of low intensity and high volume has been shown to elicit similar strength and hypertrophy benefits to traditional high-load resistance training (Madarame et al., 2008; Yamanaka, Farley, & Caputo, 2012), making BFR training a popular modality for athletes rehabilitating from injury. Alongside the benefits that BFR has for athletic populations it also has physiological benefits for the elderly population (Patterson, & Ferguson, 2011) and has been shown to prevent disuse atrophy and weakness in restricted and unused limbs (Kubota, Sakuraba, Sawaki, Sumide, & Tamura, 2008). This shows clear benefits for members of the general population as well as athletes, but training recommendations for both remain generic.

The primary mechanisms by which BFR training improves strength and hypertrophy include an increase in growth hormone concentration (Patterson, Leggate, Nimmo, & Ferguson, 2013; Takarada et al., 2000) and an accumulation of metabolites due to the anaerobic conditions created in the muscle (Loenneke, Fahs, Rossow, Abe, & Bemben, 2012). Increases in metabolites such as blood lactate not only mark a decrease in the pH of the intramuscular environment but also the stimulation of sympathetic nerve activity that plays an important role in the secretion of growth hormone (Loenneke, Wilson, & Wilson, 2010). Furthermore protein synthesis occurs as a result of BFR training via the increase in enzymes such as S6 kinase beta-1 (S6K1), an integral enzyme in the regulation of protein synthesis, and a decrease in the regulators of the mammalian target of rapamycin (mTOR) pathway (Loenneke et al., 2010). Alongside this the hypoxic conditions created by BFR exercise increase fast twitch fibre recruitment and motor unit firing rate due to the lack of available

oxygen for the slow twitch fibres and the need to compensate for the deficit in force (Loenneke et al., 2010; Moritani et al., 1992). Decreases in tissue saturation index (TSI) and an increase in electromyography (EMG) activity during BFR exercise signal these adaptations.

Combining BFR with intensitiesas low as 20% of one repetition maximum (1RM) have been shown to elicit strength benefits, while adaptations to BFR training appear to occur at a relatively faster rate than traditional resistance training (Abe et al., 2005; Cook, Kilduff, & Beaven, 2014). However it is unclear how long these adaptations are maintained upon the cessation of the BFR training programme. Interestingly the presence of BFR in exercises using greater intensities appears to have no greater effect on strength, hypertrophy or fibre recruitment than traditional high load resistance training (Laurentino et al., 2008; Yamada, Kusaka, Tanaka, Mori, Norimatsu, & Itoh, 2004). It is suggested that this occurs because greater intensities create a stimulus that causes the recruitment of higher threshold motor units and supersedes the stimulus created by BFR. It would appear that there is a maximum and an optimum range of training intensity under BFR conditions.

There is no evidence to suggest that BFR training poses any risks to healthy participants who have no history of cardiovascular disease, hypertension or blood clotting problems. In fact the physiological responses to BFR training are very similar to those seen in regular physical activity. The peripheral blood flow response to BFR exercise acts in a similar fashion to regular physical exercise while blood coagulation activity, oxidative stress and nerve conduction velocity do not appear to be adversely affected by low intensity BFR exercise (Loenneke, Wilson, Wilson, Pujol, &. Bemben, 2011). To further this, a survey of 12,642 Japanese participants who regularly partake in BFR exercise found that the most common

side effects were subcutaneous haemorrhage (13.1%) and numbness (1.3%) (Nakajima et al., 2006). These symptoms were minor and abated after the cessation of training. Interestingly the study also found that without any fatal complications BFR training has a much lower mortality rate than regular high load resistance (HLR) training, which stands at 0 – 2.5% per 10,000 (Nakajima et al., 2006). In summary, the use of BFR training protocols is perfectly safe if used in a controlled environment where pressures and intensities are closely monitored.

In recent years BFR exercise has become more popular in the strength and rehabilitation programmes of athletes of all levels. Traditionally the recommendations for improving strength and hypertrophy involve exposing the musculature to intensities of 70-80% 1RM combined with a 6-12 repetition range (Kraemer, & Ratamess, 2004). However the inclusion of BFR allows the athlete to train under a lighter intensity and achieve similar training outcomes (Kubo et al., 2006). The literature recommends many different BFR exercise protocols to achieve the greatest possible gains in strength and hypertrophy, yet these are varied in both the recommended application of load and the magnitude of BFR under which the athlete should be placed (Abe et al., 2005; Laurentino et al., 2008; Loenneke et al., 2015). While there is a great deal of variation in the literature as to the recommended pressures used in BFR exercise (Fahs, Loenneke, Rossow, Thiebaud, & Bemben, 2012), conventionally absolute cuff pressures have been used to study the effects of BFR training interventions and acute responses (Abe et al., 2005; Cook, Clark, & Ploutz-Snyder, 2007). However absolute pressures may be unreliable as individuals of differing thigh circumferences will experience different levels of BFR under the same pressure (Fahs et al., 2012) and therefore will experience potentially very different training responses. Despite this there is some agreement that the use of relative pressures using a percentage of maximum limb occlusion pressure

(LOP) is preferred as it is more specific to the individual (Scott, Loenneke, Slattery, & Dascombe, 2015).

BFR exercise has been widely studied in single-joint and isokinetic exercises, yet compound exercises such as squatting are also present in the literature (Neto et al., 2014; Yamanaka, Farley, & Caputo, 2012). The back squat is almost universally used in athletic conditioning to develop strength and power, a popularity that stems from the exercise's high transfer to athletic performance (Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004). As previously discussed, the recommendations for developing strength and hypertrophy involve resistance training at an intensity of 70-80% 1RM (Kraemer, & Ratamess, 2004) although the presence of BFR reduces this recommended intensity to 30% 1RM (Scott et al., 2015).

Takada et al. (2012) broke new ground in this area of research by comparing the effects of BFR exercise on both sprint and endurance runners. The authors found that the endurance athletes had a greater metabolic and muscle oxygenation response to the anaerobic conditions created by the BFR protocol. They elucidated that BFR exercise could be more effective in endurance runners due to the greater muscular stress that they experience when subjected to this method of training. This greater magnitude of stress was attributed to the endurance runners' higher proportion of slow twitch muscle fibres and a greater aerobic capacity. Because BFR exercise creates an anaerobic environment in the muscle cells, the sprint athletes were better able to cope with these conditions having a lower proportion of aerobic-dependent slow-twitch muscle fibres and being well conditioned to anaerobic exercise. (Takada et al., 2012).

It was decided that in order to advance our understanding of this training phenomenon, and its practical application, a greater knowledge of the responses experienced by both strength trained and endurance trained athletes was required. The current study aimed to take the ideas presented by Takada et al. (2012) but focus on the muscles responsible for locomotion such as the glutes, quadriceps and hamstrings, all also crucial to the squatting movement (Caterisano et al., 2002). In comparing the acute responses to BFR training of these two different athletic groups this study hoped to further understand how BFR training can best be used for individuals at opposite ends of the spectrum with regard to their fast or slow twitch bias and their aerobic or anaerobic capabilities. The use of the back squat makes the current study's conclusions more relatable to the daily programming of athletes, where this exercise is more commonly used, than those used in other BFR studies (Cook et al., 2007; Kubo et al., 2006; Takada et al., 2012).

The results of the Takada et al. (2012) study suggest that there is plenty of scope to discover more accurate methods for the use of BFR exercise in athletic training and rehabilitation for athletes of different phenotypes. However a drawback to this study is that the authors observed only the activity and oxygenation of the calf musculature with the athletes lying in a supine position. This limits the transferability of these results to athletic performance as there is little dynamic correspondence from exercising in this way to training and performing in an upright stance. In order to further this research it was felt that a more universal exercise protocol such as the back squat should be used, an exercise that has a high dynamic correspondence to performance and is a staple exercise in the strength and conditioning programmes of much of the athletic population.

Methods

Participants

Thirteen male participants were recruited for this study and included endurance runners (n=6) and competitive weightlifters (n=7) aged between 21 and 35 years old. The mean age of the participants was 25.5±4.7 years and informed consent was obtained from all participants prior to the beginning of the study. Anthropometric measurements including height, weight and thigh circumference were taken from every participant, and are displayed in Table 1. Ethical approval for this study was provided by St Mary's University, Twickenham.

Table 1. Mean anthropometric data

	Endurance (n=6)		**Strength (n=7)**	
	Mean	± SD	Mean	± SD
Age (yrs)	28.50	5.01	23.00	2.58
Height (cm)	179.17	6.31	181.00	6.71
Weight (kg)	72.50	4.51	84.71	7.50
10km Personal Best (mins.secs)	35.58	3.12	n/a	n/a
Training Age (yrs)	14.17	4.54	7.14	1.86
Squat 1RM (kg)	96.67	19.41	157.14	16.80
Back Squat/Body Weight Ratio	1.33	0.24	1.87	0.25
30% 1RM (kg)	29.00	5.82	47.14	5.04
80% 1RM (kg)	77.33	15.53	125.71	13.44
Max Occlusion Pressure (mmHg)	206.67	17.51	218.57	32.88
70% LOP (mmHg)	144.67	12.26	153.00	23.01
Thigh Circumference (cm)	56.42	2.76	63.79	3.00

The endurance athletes were recruited from local athletics clubs and were regular amateur competitors in the 5000m and 10,000m events. The inclusion criteria for the endurance athletes was a 10km personal best time of <40mins. This time was chosen as it represents an average running velocity of greater than 15km/h for the distance and therefore a good aerobic capacity (Conley, & Krahenbuhl, 1980). The mean 10km personal-best time for the endurance athletes was 35:58±3:12s. The weightlifters were recruited from the St. Mary's University weightlifting club and regularly participated in collegiate level weightlifting competitions. The inclusion criteria for the weightlifters was a personal best 1RM squat of >1.5 times body mass. This value was chosen as it classifies athletes as having excellent strength characteristics and therefore a greater likelihood of fast-twitch fibre dominance (Cormie, McGuigan, & Newton, 2011). The average back squat 1RM to body mass ratio of the strength athletes was 1.87±0.25. All participants completed a physical activity readiness questionnaire prior to partaking in the study. None of the participants had any previous cardiovascular diseases or any other condition that may hinder their participation in this study.

All of the endurance athletes had some previous experience in squat training and weightlifting. Each participant was carefully monitored throughout the squat protocol and was spotted by a UKSCA accredited coach to ensure correct lifting technique was maintained throughout the exercise.

Exercise Procedures

Prior to the experiment all of the participants completed a familiarisation protocol where anthropometric measurements were taken along with a back squat 1RM test and a test to determine the maximum LOP of the upper thigh. In order to establish maximum LOP

participants were asked to lie in a supine position with a 14.5cm wide blood pressure cuff (Delfi Portable Tourniquet System, Vancouver, Canada) attached to the proximal thigh just below the inguinal crease (Scott et al., 2015). A Doppler probe (Ultratec PD1, Ultrasound Technologies Ltd, Caldicot, UK) was used to detect the auscilatory pulse at the medial malleolus of the tibia for the right leg. The blood pressure cuff was inflated to 50 mmHg for 30 seconds and then increased in increments of 40 mmHg until the arterial pulse was no longer detected. The pressure was then decreased in increments of 10 mmHg until the pulse was detected again. Maximum LOP was determined as the greatest pressure at which the arterial pulse was not detected (Lixandrão et al., 2015).

The 1RM trials were conducted after the maximum LOP test in order to avoid potential miscalculations of LOP from raised blood pressure following maximal exertion. Using a goniometer each participant was asked to squat unloaded to 100° of knee flexion, a tether was raised behind the participant to contact the buttocks at this depth. This served as a marker to make them aware of the point at which they had reached 100° of knee flexion and was used for this purpose for the rest of the study. All of the participants were experienced in strength training and squatting technique, therefore the 1RM trials began at 90% of the participant's reported 1RM and the intensity was gradually increased in increments of 1-5kg until failure of the lift occurred. Lift fail was determined as the participant being unable to maintain correct form of the lift or was physically unable to lift the load. The last acceptable lift was determined as the athlete's 1RM for the purposes of this trial.

The experiment itself consisted of two separate exercise bouts: blood flow restricted (BFR) exercise and high load resistance (HLR) exercise. For the purposes of this study HLR was defined as 80% 1RM. The BFR protocol placed the participants under 70% LOP with 30% of

their 1RM on the bar, a training methodology that has been shown to enhance strength and hypertrophy (Scott et al., 2015), as well as being safe and practical in the context of a training programme (Mattar et al., 2014). Each participant performed four sets of back squat to a depth of 100° of knee flexion according to the repetition scheme 30, 15, 15, 15, this was selected as it pushes the athlete to a state of fatigue that produces the greatest metabolic accumulation (Fahs et al., 2012). 45 seconds of inter-set recovery was also selected as part of the protocol as this rest period is associated with maintaining metabolic stress (Kraemer et al., 1990). The restrictive pressure provided by the cuffs was maintained throughout the BFR protocol, including the rest periods, to maintain motor unit recruitment and the metabolic demands of the exercise (Fahs et al., 2012).

The HLR protocol again required participants to perform a squat to a depth of 100° of knee flexion but without the presence of BFR. For this protocol 80% of the participant's 1RM was placed on the bar and they performed the exercise according to a more traditional strength training protocol with the repetition scheme 7, 7, 7, 7 with 180 seconds of interest recovery (Wathen, Baechle, & Earle, 2008). These repetition schemes were selected to match total volume load between the two exercise protocols.

Prior to each experimental trial every participant performed a set of three squats at 80% 1RM without BFR. This served as the final phase of the participant's warm up and was used as a standardisation for both of the experimental trials to be measured against traditional strength training.

Data Collection

For the purposes of consistency the electrodes for the electromyography (EMG) analysis and near-infrared spectroscopy (NIRS) were placed on the right and left leg respectively for every participant during both the BFR and HLR trials.

Electromyography

To record EMG activity all participants were fitted with bipolar surface electrodes (Ag/AgCl; 10mm diameter) on the rectus femoris (RF), the vastus lateralis (VL), the semitendinosis (ST) and the gluteus maximus (GM) of the right leg. A reference electrode was placed on the anterior portion of the tibia in order to eliminate excessive electrical noise from the skin. All electrodes were placed according to the seniam guidelines for electrode placement (http://seniam.org/sensor_location.htm). Before the electrodes were put in place the skin was shaved and cleaned with an alcohol wipe. Electrodes were placed 20mm apart and parallel to the fibre direction. EMG signals were measured at a sampling frequency of 1000Hz using a data acquisition system (Biopac MP150, Biopac Systems Inc, CA, USA). Before EMG analysis was taken participants were asked to perform three unloaded squats in order to detect muscle activity and to eliminate excessive noise. EMG was collected for three repetitions at each participant's 80% 1RM squat which served as a dynamic normalisation against which the EMG amplitudes of the subsequent exercise condition were compared. EMG was collected for the last two repetitions of every set for both the BFR and HLR experiments. The peak electrical activity for each muscle was taken from the onset of the first repetition to the cessation of the second repetition. This data was then expressed as a percentage against the normalisation value.

Near-infrared Spectroscopy

Muscle tissue saturation index (TSI) was used as a representation of the relative concentration of oxyhaemoglobin in relation to the total amount of haemoglobin in the tissue (Scott, Slattery, Sculley, Lockie, & Dascombe, 2014). TSI was continuously monitored in the distal portion of the VL of the left leg during both exercise procedures using a wireless spatially resolved dual-wavelength spectrometer (Portamon, Artinis Medical Systems, BV, The Netherlands). The NIRS device was placed on the VL using the same placement technique described above for the EMG electrodes according to the seniam guidelines (http://seniam.org/sensor_location.htm) for the VL. The area in which the device was to be placed was shaved and cleaned with an alcohol wipe to minimise the disruption of the signal. A black cloth was also secured over the device so as to eliminate contamination from ambient light. TSI measurements using the same device as the present study has been shown to be a reliable and reproducible technique to measure muscle oxygenation during exercise (Southern, Ryan, Reynolds, & McCully, 2014). TSI has been shown to be the most reliable variable derived from NIRS analysis (Scott et al., 2014) a fact that determined its inclusion within the current study.

Changes in TSI (expressed as a percentage) from resting values were measured using 750nm and 850nm wavelengths as absorption is not influenced by skin blood flow at these wavelengths (Mancini, Bolinger, Li, Kendrick, Chance, & Wilson, 1994). An arbitrary value for the differential pathlength was used and was set to 3.83 (Patterson, Bezodis, Glaister, & Pattison, 2015). TSI was standardised during 5 minutes of rest as the participant was being prepared for the exercise protocol. This figure served as a resting value and was used as a comparison for both the BFR and HLR trials. All data were collected at 10Hz and were averaged over the course of the preparatory period which served as a resting value, as well as

for each set of both exercise conditions, not including the inter-set recovery periods. The data for each set is presented as the difference between resting and exercising values.

Blood Lactate

Blood lactate (BL) was collected from all participants for both the BFR and the HLR experimental trials and served as a marker of the metabolic stress. Collection occurred at rest immediately before the first set and again between 60 and 120 seconds after the last set of each experiment. This time period ensured that venous blood flow returned to normal after exercising so that sample collection was not compromised by the distal pooling of metabolites in the limbs. Prior to collection the participant's index finger was cleaned with an alcohol wipe and pricked with a lancet. A vial was then filled with 20µl of blood and analysis was performed within one hour of collection using a blood lactate analyser (Biosen C-Line, EKF Diagnostics, Cardiff, UK). All blood samples and any sharp implements were discarded of responsibly. All necessary health and safety protocols were adhered to during this process.

Statistical Analysis

Prior to analysis all data were tested for normality using the Kolmogorov-Smirnov test and any data that were not normally distributed were log transformed to reduce non-uniformity of error. Interaction and differences between groups, conditions and all time points were tested for TSI and EMG using a 4x2 way ANOVA and BL using a 2 way ANOVA. Tukey's post-hoc test was performed to discover any differences between groups. Relationships between variables for both groups were examined by linear regression using the Pearson test. The alpha level for statistical significance was set at 0.05 for all of the statistical tests. All statistics were calculated using SPSS 22 (IBM SPSS Statistics 22.0 for Windows, Chicago, IL).

Results

As Table 2 shows, peak activation of VL, RF and GM in the BFR protocol is significantly reduced to 75.06±5.57% ($F=105.96$), 42.08±12.18% ($F=45.78$), and 32.15±21.07% ($F=285.94$) respectively compared to their levels of activation during the 80% standard trial ($p<0.05$). ST displayed no significant changes to activation across any condition or time point. There is no significant difference between groups across the two conditions for any time point, meaning that these decreases in activation are likely due to the decrease in intensity rather than the presence of BFR conditions.

Table 2.Mean peak EMG activity for all groups, conditions and time points

	Normalisation (v)	BFR Protocol				
		SET 1 (%)	SET 2 (%)	SET 3 (%)	SET 4 (%)	Protocol Average (±SD)
Endurance						
Vastus Lateralis	0.901	74.03 [a b]	69.92 [a b]	66.15 [a b]	77.25 [a b]	75.06±5.57
Rectus Femoris	1.523	63.23 [a b]	34.27 [a b]	27.77 [a b]	37.82 [a b]	42.08±12.19
Gluteus Maximus	0.941	13.60 [a b]	12.33 [a b]	13.71 [a b]	10.73 [a b]	32.15±21.07
Semitendinosis	0.785	27.28 [a]	26.13 [a]	30.34 [a]	26.00 [a]	40.51±14.87
Strength						
Vastus Lateralis	0.836	75.00 [a b]	80.98 [a b]	83.37 [a b]	73.80 [a b]	
Rectus Femoris	0.941	51.12 [a b]	50.58 [a b]	42.19 [a b]	29.65 [a b]	
Gluteus Maximus	0.190	50.53 [a b]	47.89 [a b]	56.84 [a b]	51.58 [a b]	
Semitendinosis	0.318	40.53 [a]	51.22 [a]	68.19 [a]	54.36 [a]	
		HLR Protocol				
		SET 1 (%)	SET 2 (%)	SET 3 (%)	SET 4 (%)	Protocol Average (±SD)
Endurance						
Vastus Lateralis	0.901	105.99 [a]	92.23 [a]	100.11 [a]	85.13 [a]	100.34±7.63
Rectus Femoris	1.523	76.43 [a]	94.94 [a]	70.12 [a]	98.49 [a]	105.02±22.09
Gluteus Maximus	0.941	37.41 [a]	24.97 [a]	39.96 [a]	28.80 [a]	71.72±39.39
Semitendinosis	0.785	112.94 [a]	113.19 [a]	112.94 [a]	60.93 [a]	100.00±16.96
Strength						
Vastus Lateralis	0.836	100.12 [a]	105.50 [a]	103.23 [a]	110.41 [a]	
Rectus Femoris	0.941	117.85 [a]	131.56 [a]	128.91 [a]	121.89 [a]	
Gluteus Maximus	0.190	113.68 [a]	118.42 [a]	103.16 [a]	107.37 [a]	
Semitendinosis	0.318	93.95 [a]	109.66 [a]	106.21 [a]	90.18 [a]	

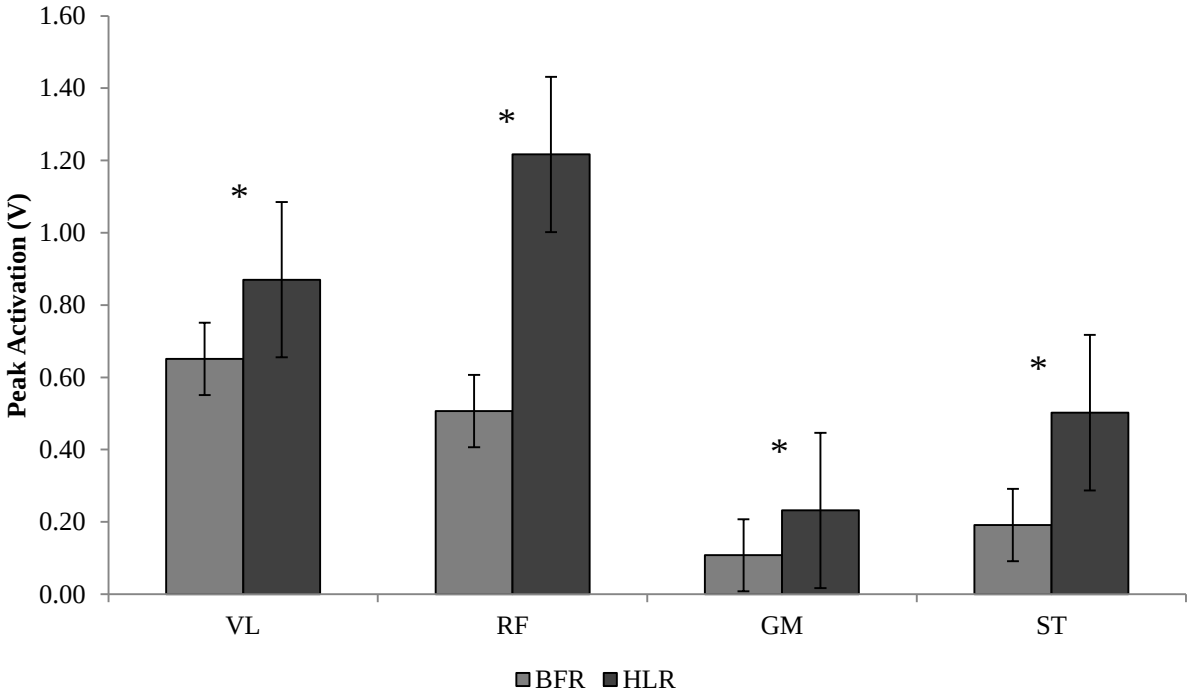
[a] Significant difference between corresponding time points for each exercise condition

[b] Significant difference from 80% standardisation.

There was a significant difference between the exercise conditions for VL (F=7.51), RF (F=18.90), GM (F=225.53) and ST (F=8.18) across both groups ($p<0.05$), with the BFR condition producing significantly smaller EMG activity for each muscle ($p<0.05$) (see Figure 1). Further to this the endurance group showed greater recruitment of GM and ST across all

four sets of the BFR protocol compared to the strength group, however this was not to the level of significance.

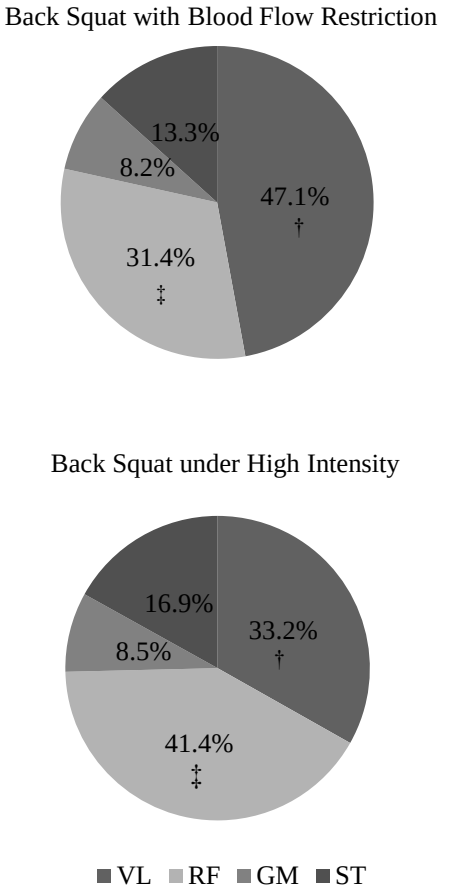
Figure 1.Peak activation for both BFR and HLR conditions.



*Represents significant difference between exercise conditions.

As shown in Figure 2, under BFR conditions the contribution of VL to the total activity of the movement (47.1±2.7%) is significantly increased compared to its contribution under HLR conditions (33.2±2.3%, $F=9.62$, $p<0.05$). Alongside this Figure 2 also displays the contribution of RF to the movement significantly increases under HLR conditions when compared to BFR conditions across both groups (41.4±1.1% vs 31.4±5.4% respectively, $F=6.97$, $p<0.05$). The contribution of both GM and ST remains similar across both conditions for both groups at all time points.

Figure 2.Contribution to the total activity of the movement for both BFR and HLR conditions.



†Significant difference for VL between conditions

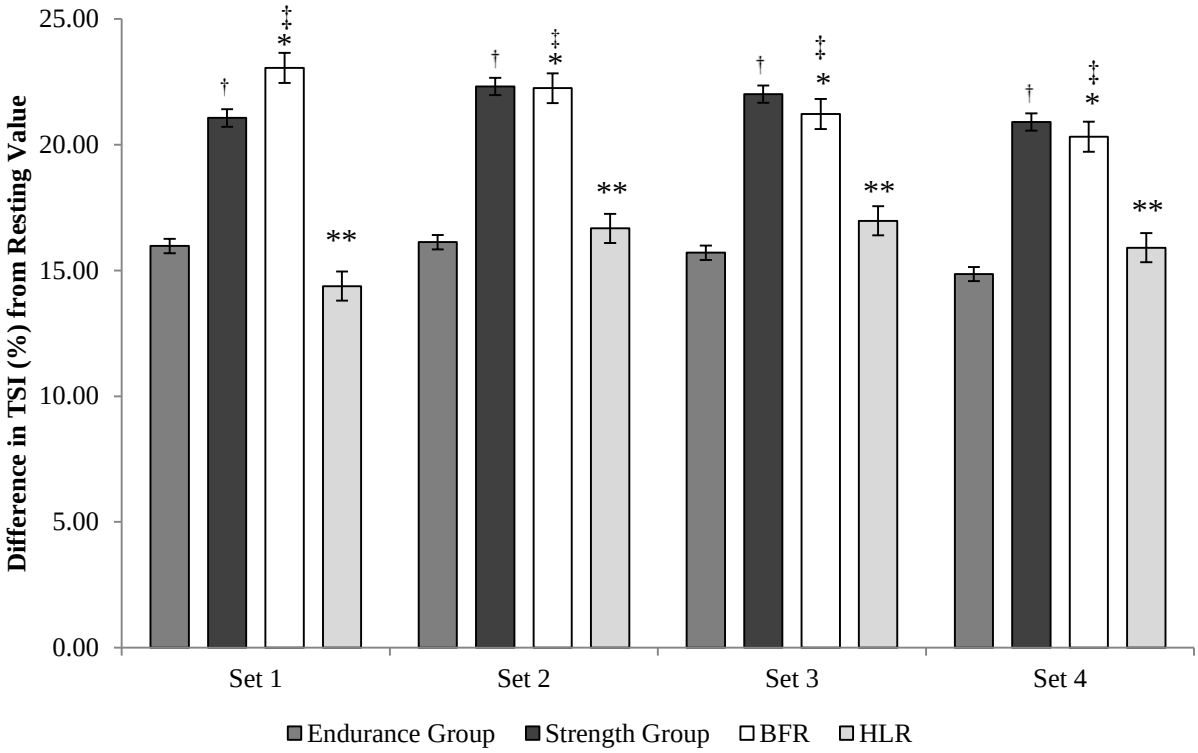
‡Significant difference for RF between conditions

Further to this, the strength group displayed a significantly greater contribution of the VL to total electrical activity across both exercise conditions (43.7±2.4%) compared to the endurance group (36.0±2.6%, $F=4.69$, $p<0.05$) as shown in Table 2.

BFR conditions caused significantly greater mean decreases in TSI from resting conditions compared to the HLR protocol ($F=118.90$, $p<0.05$). Further to this, as shown in Figure 3, when paired with corresponding sets across protocols the BFR protocol produced

significantly greater decreases in TSI than the HLR protocol (F=28.06, p<0.05). The strength group showed significantly greater differences to resting values (17.0±1.2%) compared to the endurance group (12.9±1.3%) across both conditions (F=5.46, p<0.05) (see Figure 3). However there was no significant difference between groups within each exercise condition.

Figure 3.Differences in TSI from resting values for both groups between conditions and both conditions between groups across all time points



*Significantly greater difference in TSI from HLR protocol.

†Significantly greater difference in TSI from endurance group.

**Significant difference to all other time points for HLR protocol

‡Significant difference to all other time points for BFR protocol

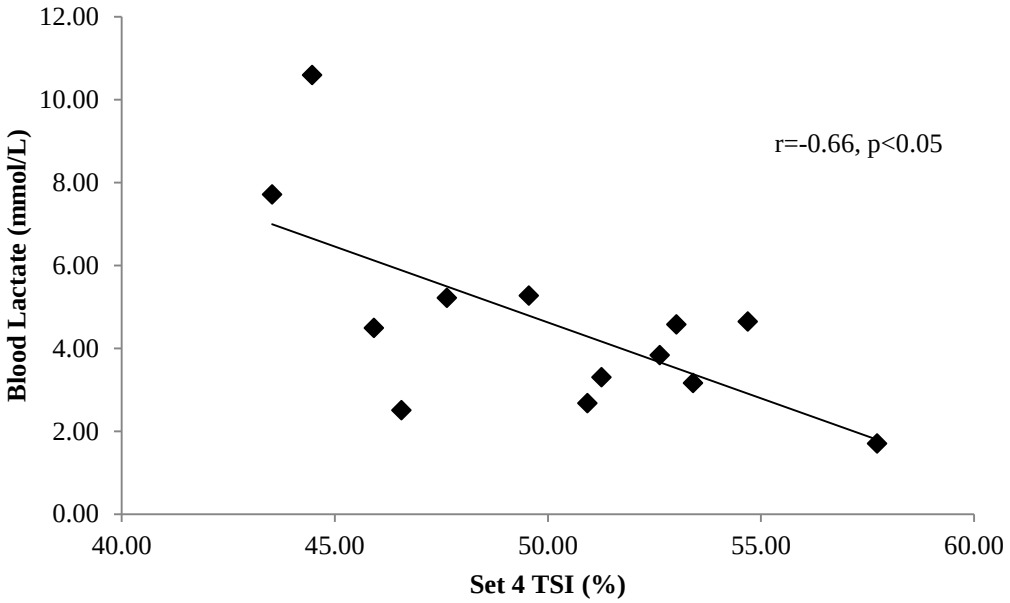
There was a significant difference between each time point for within each exercise protocol (F=39.67, p<0.05). During the BFR protocol there was an initial substantial decrease in TSI from resting values during the first set followed by a sequential decrease in the difference to

resting values for the following sets (see Figure 3). Interestingly the values for the HLR protocol resemble a reverse pattern, with an increase in the difference to resting values as the protocol progressed, with a slight decrease in the difference to resting values during the fourth set (see Figure 3).

BL concentrations post-exercise were significantly greater than resting values for both exercise conditions ($F=39.26$, $p<0.05$). However there was no significant difference between the two groups for post-exercise BL values for either exercise condition. Further to this the BFR protocol produced significantly greater levels of BL for both groups compared to the HLR protocol ($F=5.41$, $p<0.05$).

There was a significant negative correlation ($r=-0.66$, $p<0.05$) between blood lactate collected immediately after the BFR protocol and the TSI of the final set of the BFR protocol (Figure 4). Alongside this there was no significant correlation between the blood lactate collected after the HLR protocol and the TSI of any set of the HLR protocol. There were also no significant relationships between BL and EMG or EMG and TSI when paired for the same time points in either group or exercise condition.

Figure 4.Relationship between average TSI (%) during Set 4 of BFR protocol and BL collected post-exercise



Discussion

The impetus for this study derived from the need to further understand the effect that BFR training has on athletes of differing muscle fibre type and metabolic physiology. Previously much of the literature regarding BFR training has focussed primarily on generic exercise recommendations for all users. This study aimed to shed further light on how athletes from different ends of the physiological spectrum respond to BFR training and as such provide training recommendations that will provide the greatest acute stimulus and the greatest training response to these individuals.

Suga et al. (2009) found that metabolic stress during low intensity resistance exercise was significantly increased when BFR was applied, but not to the same level as that seen for high intensity resistance exercise. The authors recommend that a protocol of moderate BFR should be combined with intensities of 30% 1RM or above to provide enough of a metabolic response to replace high intensity resistance exercise as a training modality (Suga et al., 2010). The results of the current study saw a significant increase in BL for both exercise conditions, yet the BFR protocol, which utilised an intensity of 30% 1RM, caused significantly greater increases in BL compared to HLR. This result agrees with the findings of Suga et al. (2010) in that the same relative 1RM intensity produced a significant dose-response effect in BL for both groups of athletes. Furthermore, as discussed earlier, this data signals the stimulation of the sympathetic nervous system, a mechanism that leads to the secretion of growth hormone and enzymes such as S6K1 which is responsible for protein synthesis (Loenneke et al., 2010). This demonstrates that strength and hypertrophy adaptations would occur should the athlete utilise this BFR modality within a longitudinal training programme.

One hypothesis of the current study was that the endurance cohort would experience a greater increase in BL that the strength cohort due to being unused to the anaerobic conditions created by BFR exercise. This was based on evidence presented by Kadoguchi et al. (2010) who saw greater metabolic stress in endurance runners with a high aerobic capacity after performing low intensity resistance exercise with BFR compared to sprint athletes. This was manifested as a significant depletion in phosphocreatine compared to the sprint group. Similar results were seen by Takada et al. (2012) where the endurance athletes, who are slow-twitch fibre dominant, experienced greater metabolic stress as a result of the BFR exercise protocol. However the results of the present study show that there is no significant difference between groups for either exercise condition. For strength trained athletes performing 75 repetitions during the BFR protocol is extremely metabolically taxing, allied to this the anaerobic environment created in the muscles of the endurance cohort also causes a substantial metabolic response. Therefore it is possible that the reason for both strength and endurance cohorts displaying such similar BL responses during the BFR protocol is because each group experienced a greater metabolic demand from the exercise but for different reasons.

The increases in metabolic stress seen under BFR conditions are a result of the anaerobic environment created in the muscle cells. Of the two exercise conditions used in the current study the athletes spent more time under the bar during the BFR protocol. Although this does not equate to greater EMG activity, greater leg intramuscular pressures maintained for longer durations produces significantly greater decreases in TSI from resting values (Macias et al., 2012). The results show that at 70% LOP there are significant decreases in TSI under BFR conditions which are maintained for a greater period of time than during a traditional HLR protocol. Furthermore, TSI continues to decrease under BFR conditions for subsequent

exercise sets meaning exposure to an anaerobic stimulus is increased over time. A significant negative correlation was discovered between TSI during the final set of the BFR exercise protocol and BL concentration. This further reinforces the evidence that BFR conditions are responsible for increasing metabolic stress and driving physiological adaptations in strength and hypertrophy (Loenneke et al., 2012; Patterson et al., 2013). If this result was a consequence of the number of repetitions performed during the BFR protocol one would expect the strength athletes to respond to a greater degree than the endurance group. As there is no significant difference between the two groups it seems unlikely that this is the case. Instead, because there is a gradual decrease in TSI during BFR exercise it appears that there is a threshold for TSI below which BL exponentially increases. Future studies should seek to collect blood lactate at every time point so as to determine if the relationship between BL and TSI begins sooner in the exercise bout.

The influence of metabolic stress during BFR exercise spreads further than the muscles distal to the tourniquet. The increases in metabolite concentrations have been suggested to enhance the training effects on the proximal muscles pertaining to the trunk and the spine via increases in growth hormone and metabolic products (Madarame et al., 2008; Takarada et al., 2000). Furthermore the proximal musculature of the upper body has been shown to respond at different rates to the muscles of the arm when BFR is applied to the bench press exercise (Yasuda, Ogasawara, Sakamaki, Bemben, & Abe, 2011). There are clearly major differences in the biomechanics of the upper and lower limbs that may be the reason for BFR conditions having a greater effect on the chest, though it is beyond the scope of this discussion to analyse these specific differences. Notwithstanding this, the current study found no significant increases in the recruitment of the muscles located proximal to the tourniquet, namely the GM. As previously discussed the endurance athletes displayed a non-significant

increase in GM recruitment under BFR conditions, however it is unclear whether this is due to a lack of resistance training proficiency or a direct effect of BFR. A larger cohort of endurance athletes would be needed to decipher this.

Athletes who are well trained in the squat display greater activation of the agonists under both maximal and submaximal loads compared to individuals with a lower squatting ability (Clark, Lambert, & Hunter, 2012). The current study reinforces this, as the strength group performed both the BFR and HLR protocols with a significantly greater contribution of the VL to the total electrical activity than the endurance group. It was also observed that the endurance group displayed greater amplitudes for the GM and ST across all time points under BFR conditions, though these results were not to the level of statistical significance. Notwithstanding this, these results suggest that the greater EMG activity of the GM and ST show that the endurance athletes employed a different motor unit recruitment strategy to the strength athletes who are able to maintain the lift by more efficiently recruiting the quadriceps, a strategy that is most efficient when squatting to a depth of 100° (Bryanton, Kennedy, Carey, & Chiu, 2012). This occurs because strength trained athletes are able to more efficiently recruit the relevant motor units during weightlifting movements due to a greater neural excitability and downregulation of inhibitory motor pathways compared to athletes of lesser weightlifting proficiency (Aagaard, 2003).

It has been suggested that exercise under BFR conditions increases the preferential recruitment of type II motor units (Yamada et al., 2004). However, across the entire cohort the peak activation of VL, RF and GM were significantly reduced during the BFR protocol with respect to the electrical activity seen during the 80% 1RM standardisation. There is no significant difference between groups for this, meaning that these decreases in activation are

likely due to the decrease in intensity, and consequently reduced motor unit recruitment, rather than the presence of BFR conditions. Motor units are recruited sequentially based on the relative intensity of the lift. Slow twitch fibres are recruited first, followed by fast twitch fibres as intensity increases (Loenneke et al., 2010). Therefore it appears that these decreases in electrical activity are due to reduced motor unit recruitment under BFR conditions.

The current study adds to the considerable literature showing that activation of the muscles of the lower limbs increases as a consequence of increases in external load. This is demonstrated by the significant increases in peak EMG activity under HLR conditions compared to BFR. There is some interaction between the VL and RF depending on the exercise conditions, with VL providing a greater proportion of the total activation during BFR exercise while RF is dominant during HLR squatting. Both squatting protocols were deliberately set to the same depth for the purposes of a direct comparison between the two. It has been shown that the relative muscular effort of the knee extensors is greatest at similar squatting depths to the present study (Bryanton et al., 2012). As RF is the only muscle in the quadriceps group that is bi-articular the HLR protocol requires its increased contribution in order to overcome a greater load. Furthermore the low contribution of the hamstrings observed in the current study concurs with conclusions made by Bryanton, Kennedy, Carey, and Chiu (2015) that the activation of these muscles should be minimised when squatting in order to reduce their co-contraction at the knee and produce a more efficient movement.

In a study utilising a low-intensity shallow squat protocol to 130° knee flexion Rittweger, Moss, Colier, Stewart, and Degens (2010) found that NIRS variables remained constant throughout the exercise procedure. The results of the current study found that neither the HLR nor BFR conditions maintained a constant value for TSI and that both caused a

significant decrease in TSI from resting values. For the HLR protocol to create a significant decrease in TSI was unexpected. However it can be explained by elevations in intramuscular pressure that occur during exercise and are likely generated by local muscle tissue deformation due to muscle force development (Ballard, Watenpaugh, Breit, Murthy, Holley, & Hargens, 1998). To further this, lower limb intramuscular pressures have been shown to increase under greater exercise intensities (Macias et al., 2012). This confirms that the significant decreases in TSI seen during HLR exercise were caused by the greater muscular recruitment seen during this protocol. Rittweger et al. (2010) found that NIRS variables were maintained due to the very low intensity utilised by the authors. Therefore, without the presence of BFR TSI and other NIRS variables will only decrease under greater muscular contractions such as those produced during 80% 1RM intensity exercise.

The present study found very few significant differences between the strength and endurance groups for either BFR or HLR exercise. This reinforces the need for BFR exercise prescription to be based on relative intensities and LOPs rather than absolute values. Relative LOP is as important to BFR training as relative intensity is to traditional strength training. Because of the role that LOP plays in creating the training stimulus in BFR training (Scott et al., 2015), its application should be individualised to each athlete just as the application of intensity is in HLR training. There is a consensus in the literature that individualised LOPs are more appropriate within a BFR training protocol compared to absolute pressures (Fahs et al., 2012; Scott et al., 2015). Alongside this, LOP has been attributed as the influencing factor in driving BFR training adaptations (Wernbom, Augustsson, & Thomeé, 2006) and training adaptations are optimised at 70% of maximum LOP (Scott et al., 2015). This evidence, coupled with the results of the current study demonstrate that 70% of maximum LOP is the most effective relative occlusion pressure with which to perform BFR training.

The results of the current study suggest that at the systemic level generic exercise recommendations have an equal effect regardless of the physiology of the athlete. Therefore, the BFR protocol presented here is recommended for inclusion in the training programmes of athletes as it creates the reductions in TSI and increases in metabolic stress that are necessary to stimulate long-term physiological adaptations. Following a bout of BFR exercise knee extension torque recovers after one hour post-exercise and reaches baseline levels after 24 hours (Loenneke, Thiebaud, Fahs, Rossow, Abe, & Bemben, 2013). This shows that the application of BFR can be a repeatable exercise protocol that does not reduce the athlete's training time any more than traditional resistance exercise does. In conclusion BFR exercise should be considered a repeatable and manageable training modality that should be subject to the principles of overload, progression and dynamic correspondence.

A limitation of this study was the placement of the NIRS device. Muscle tissue oxygenation for the VL has been shown to be non-uniform during exercise (Kennedy, Haykowsky, Boliek, Esch, Scott, & Warburton, 2006; Miyamoto, Wakahara, Ema, & Kawakami, 2013). The distal portion of the VL has been shown to have significantly lower oxygen saturation during exercise than the middle or proximal portions, whereas neuromuscular activation is consistent throughout the muscle (Kennedy et al., 2006; Miyamoto et al., 2013). This could limit the findings of the current study with regard to TSI, however to combat this it was ensured that the placement of the NIRS device was consistent for every participant, making the data consistent and reliable. Further to this, there is much evidence in the literature to suggest that restrictive cuff size should be individualised to each participant based on thigh circumference (Fahs et al., 2012). The 14.5cm cuffs used for this experiment (Delfi Portable Tourniquet System, Vancouver, Canada) were the only brand available, meaning this individualisation

was not an option for this experiment. Another oversight was that the collection of EMG data occurred during the final two repetitions of each set for both exercise protocols. It is possible that this may influence the findings of the study as the athlete would experience a greater degree of fatigue during the final rep of the set compared to the penultimate rep. Because peak EMG amplitude was collected for both reps there is no certainty that the data collected was from the final rep.

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Websites

http://seniam.org/sensor_location.htm

Appendices

Appendix A

St Mary's University

Ethics Sub-Committee

Application for Ethical Approval (Research)

This form must be completed by any undergraduate or postgraduate student, or member of staff at St Mary's University, who is undertaking research involving contact with, or observation of, human participants.

Undergraduate and postgraduate students should have the form signed by their supervisor, and forwarded to the School Ethics Sub-Committee representative. Staff applications should be forwarded directly to the School Ethics Sub-Committee representative. All supporting documents should be merged into one PDF (in order of the checklist) and clearly entitled with your **Full Name, School, Supervisor.**

Please note that for all undergraduate research projects the supervisor is considered to be the Principal Investigator for the study.

If the proposal has been submitted for approval to an external, properly constituted ethics committee (e.g. NHS Ethics), then please submit a copy of the application and approval letter to the Secretary of the Ethics Sub-Committee. Please note that you will also be required to complete the St Mary's Application for Ethical Approval.

Before completing this form:

- Please refer to the **University's Ethical Guidelines**. As the researcher/ supervisor, you are responsible for exercising appropriate professional judgment in this review.
- Please refer to the Ethical Application System (Three Tiers) information sheet.
- Please refer to the Frequently Asked Questions and Commonly Made Mistakes sheet.
- If you are conducting research with children or young people, please ensure that you read the **Guidelines for Conducting Research with Children or Young People**, and answer the below questions with reference to the guidelines.

Please note:

In line with University Academic Regulations the signed completed Ethics Form must be included as an appendix to the final research project.
If you have any queries when completing this document, please consult your supervisor (for students) or School Ethics Sub-Committee representative (for staff) .

St Mary's Ethics Application Checklist

The checklist below will help you to ensure that all the supporting documents are submitted with your ethics application form. The supporting documents are necessary for the Ethics Sub-Committee to be able to review and approve your application.

Please note, if the appropriate documents are not submitted with the application form then the application will be returned directly to the applicant and may need to be re-submitted at a later date.

	Enclosed? (delete as appropriate)		Version No
Document	Yes	Not applicable	
1.Application Form	Mandatory		
2.Risk Assessment Form	Yes		
3.Participant Invitation Letter	Yes		
4.Participant Information Sheet	Mandatory		
5.Participant Consent Form	Mandatory		
6.Parental Consent Form		Not applicable	
7.Participant Recruitment Material - e.g. copies of Posters, newspaper adverts, website, emails		Not applicable	
8.Letter from host organisation (granting permission to conduct the study on the premises)		Not applicable	
9. Research instrument, e.g. validated questionnaire, survey, interview schedule		Not applicable	
10.DBS included		Not applicable	
11.Other Research Ethics Committee application (e.g. NHS REC form)		Not applicable	

I can confirm that all relevant documents are included in order of the list and in one PDF document entitled with you: ***Tristan Baker, School of Sport, Health and Applied Sciences, Stephen Patterson***

Signature of Applicant: Tristan Baker, MSc in Strength and Conditioning

Signature of Supervisor: 

Ethics Application Form

1) Name of proposer(s)	Tristan Baker
2) St Mary's email address	135186@live.stmarys.ac.uk
3) Name of supervisor	Dr. Stephen Patterson

4) Title of project: **How does blood flow restriction exercise and high load resistance training effect muscle activation patterns and oxygenation in endurance and weightlifting athletes?**

5) School or service	School of Sport, Health and Applied Sciences
6) Programme (if undergraduate, postgraduate taught or postgraduate research)	Strength and Conditioning Masters
7) Type of activity/research (staff / undergraduate student research / postgraduate student)	Postgraduate Student
8) Confidentiality	
Will all information remain confidential in line with the Data Protection Act 1998	YES

9) Consent	
Will written informed consent be obtained from all participants / participants' representatives?	YES

10) Pre-approved protocol	
Has the protocol been approved by the Ethics Sub-Committee under a generic application?	YES Date of approval: 10.5.12

11) Approval from another Ethics Committee	
a) Will the research require approval by an ethics committee external to St Mary's University?	NO
b) Are you working with persons under 18 years of age or vulnerable adults?	NO

12) Identifiable risks	
a) Is there significant potential for physical or psychological discomfort, harm, stress or burden to participants?	NO
b) Are participants over 65 years of age?	NO
c) Do participants have limited ability to give voluntary consent? This could include cognitively impaired persons, prisoners, persons with a chronic physical or mental condition, or those who live in or are connected to an institutional environment.	NO
d) Are any invasive techniques involved? And/or the collection of body fluids or tissue?	YES – collection of blood for analysis of blood lactate.
e) Is an extensive degree of exercise or physical exertion involved?	YES
f) Is there manipulation of cognitive or affective human responses which could cause stress or anxiety?	NO

g) Are drugs or other substances (including liquid and food additives) to be administered?	NO
h) Will deception of participants be used in a way which might cause distress, or might reasonably affect their willingness to participate in the research? For example, misleading participants on the purpose of the research, by giving them false information.	NO
i) Will highly personal, intimate or other private and confidential information be sought? For example sexual preferences.	NO
j) Will payment be made to participants? This can include costs for expenses or time.	NO
k) Could the relationship between the researcher/ supervisor and the participant be such that a participant might feel pressurised to take part?	NO

13) Proposed start and completion date

Please indicate:

- When the study is due to commence.
- Timetable for data collection.
- The expected date of completion.

Please ensure that your start date is at least 3 weeks after the submission deadline for the Ethics Sub-Committee meeting.

Start Date: 8th February 2016

Data collection until 3rd April 2016

Submission of study 8th May 2016

14)Sponsors/Collaborators

Please give names and details of sponsors or collaborators on the project. This does not include you supervisor(s) or St Mary's University.

- Sponsor: An individual or organisation who provides financial resources or some other support

for a project.
- Collaborator: An individual or organisation who works on the project as a recognised contributor by providing advice, data or another form of support.

Collaborators: Dr Stephen Patterson (stephen.patterson@stmarys.ac.uk), Tristan Baker (135186@live.stmarys.ac.uk), Will Page (william.page@stmarys.ac.uk)

15. Other Research Ethics Committee Approval

- Please indicate whether additional approval is required or has already been obtained (e.g. the NHS Research Ethics Committee).
- Please also note which code of practice / professional body you have consulted for your project
- Whether approval has previously been given for any element of this research by the University Ethics Sub-Committee.

Not Applicable

16. Purpose of the study

In lay language, please provide a brief introduction to the background and rationale for your study.

- Be clear about the concepts / factors / performances you will measure / assess/ observe and (if applicable), the context within which this will be done.
- Please state if there are likely to be any direct benefits, e.g. to participants, other groups or organisations.

In recent years blood flow restriction (BFR) training has become more commonplace in strength and rehabilitation programmes for athletes. Takada et al. (2012) presented a blood flow restriction study that compared sprinters and endurance runners performing plantarflexion under BFR conditions with low load and without BFR with a high load. The study found significant differences between the two subject groups for oxygen saturation in the blood during the BFR exercise and concluded that it has a greater effect on endurance runners than sprinters because of their greater aerobic capacity.

This study aims to take the ideas presented by Takada et al. (2012) but focus on the muscles responsible for locomotion (the quadriceps and hamstrings) as opposed to the muscles of the lower leg. We will fit occlusion cuffs to the upper thigh in order to examine oxygen saturation in the blood during and the electromyography (EMG) activity of the quadriceps and hamstrings during a back squat exercise. The outcome of the study will be a comprehensive comparison of the responses to BFR exercise between predominantly slow twitch, aerobic athletes and fast twitch, anaerobic athletes.

The use of the back squat in this study will make the conclusions more relatable to the daily programming of athletes where this sort of exercise is more commonly used than those used in other BFR studies (Cook et al. 2007; Kubo et al., 2006; Takada et al., 2012).

In comparing the acute responses to occlusion training of these two different subject groups this study hopes to further understand how occlusion training can best be used for individuals at opposite ends of the spectrum with regard to their fast or slow twitch bias and their aerobic/anaerobic capabilities. A greater knowledge of this will help with the prescription of occlusion training during periods of rehabilitation or alternative training programmes.

17. Study Design/Methodology

In lay language, please provide details of:

a) The design of the study (qualitative/quantitative questionnaires etc.)
b) The proposed methods of data collection (what you will do, how you will do this and the nature of tests).
c) You should also include details regarding the requirement of the participant i.e. the extent of their commitment and the length of time they will be required to attend testing.
d) Please include details of where the testing will take place.
e) Please state whether the materials/procedures you are using are original, or the intellectual property of a third party. If the materials/procedures are original, please describe any pre-testing you have done or will do to ensure that they are effective.

Anthropometric measurements will be taken from every subject. Thigh circumference will be measured for both limbs to ensure the correct sized pressure cuff will be assigned to each participant.

For the purposes of consistency the electrodes for the electromyography (EMG) analysis and near-infrared spectroscopy (NIRS) will be placed on the right and left leg respectively for every subject during each trial.

Exercise Procedures

Prior to the experiment all of the participants will complete a familiarisation protocol where anthropometric measurements are to be taken along with a back squat one rep max (1RM) test and a test to determine the maximum arterial occlusion pressure of the thighs.

The experiment itself will consist of two exercise bouts, one of which place the participants under blood flow restriction (BFR) conditions while squatting 30% 1RM, and a second which involves a squat trial without BFR at 80% 1RM (HLRT). This will serve as a comparison for both groups to traditional resistance training.

All loads and pressures will be individualised for each participant based on their 1RM score and maximum arterial occlusive pressure. 30% 1RM will be used for the BFR trial as this intensity has been shown to elicit a strong training response (Scott et al., 2015). The BFR trial will use 40% arterial occlusion pressure (Laurentino et al., 2012). Four sets will be used in the BFR trial with a rep range of 30,15,15,15 with 45 seconds recovery between each set. The HLRT trial will us a rep range of 4 sets each of 7 reps in order to match the volume load lifted in each trial (number of sets x number of reps x load in Kg). The period of rest between each set for the HLRT trial will be 180 seconds. Similar protocols have been shown to elicit substantial improvements in strength and hypertrophy (Shoenfeld, 2010).

Prior to beginning each trial participants will be fitted with an occlusion cuff at the inguinal crease of each thigh which will be inflated to the relevant pressure for that exercise bout. Once the cuffs are fitted they will not be removed for the duration of the exercise bout, including during inter-set rest periods.

For the HLRT trial the subjects will be fitted with the same EMG and NIRS electrodes but will not be fitted with occlusion cuffs.

Data Collection

EMG and NIRS measurements will be taken for every rep during every set for each participant.

Electromyography

To record EMG activity all participants will be fitted with bipolar surface electrodes (Ag/AgCl; 10cm diameter) on the rectus femoris (RF) and the biceps femoris (BF) of the right leg. Before the electrodes are put in place the skin was lightly abraded with sand paper and then cleaned with an alcohol wipe. Electrodes were placed 2cm apart and parallel to the fibre direction while the ground electrode was placed on the tibial tuberosity of the right leg.

Near-infrared Spectroscopy

Muscle oxygenation was monitored in the RF of the right leg during each exercise bout using NIRS. The NIRS probes will be placed on the largest circumference of the subjects' thigh below the occlusion cuff. The distal probe will be placed on the distal third of the RF muscle with the center of the probe 20cm above the patella of the left leg. The center of the proximal probe will be placed 10cm from the center of the distal probe. Both areas underneath the probes are to be shaved to minimise disruption of the signal and adipose tissue thickness will be measured with Harpenden skinfold calipers to ensure that adipose tissue thickness is less than 1.5cm.

18. Participants

Please mention:

a) The number of participants you are recruiting and why. For example, because of their specific age or sex.
b) How they will be recruited and chosen.
c) The inclusion / exclusion criteria's.
d) For internet studies please clarify how you will verify the age of the participants.
e) If the research is taking place in a school or organisation then please include their written agreement for the research to be undertaken.

Twenty male subjects (aged 18-29) will be recruited for this study (endurance runners n=10; Olympic weightlifters n=10). The endurance athletes will be recruited from local athletics clubs and inclusion criteria will be a self-reported 10km time of less than 40 minutes. The Olympic lifters will be recruited from the St. Mary's University weightlifting club and should have a 1RM back squat of at least 1.5 times their body weight. Exclusion criteria will be not meeting the above inclusion criteria, any lower limb injury within the last two years, any history of cardiovascular disease and indicating any other reason why they may not participate in the study on the physical activity readiness questionnaire (PARQ).

Informed consent will also be obtained from all participants prior to the beginning of the study.

19. Consent

If you have any exclusion criteria, please ensure that your Consent Form and Participant Information Sheet clearly makes participants aware that their data may or may not be used.

a) Are there any incentives/pressures which may make it difficult for participants to refuse to take part? If so, explain and clarify why this needs to be done
b) Will any of the participants be from any of the following groups?
   - Children under 18
   - Participants with learning disabilities
   - Participants suffering from dementia
   - Other vulnerable groups.
c) If any of the above apply, does the researcher/investigator hold a current DBS certificate? A copy of the DBS must be included with the application.
d) How will consent be obtained? This includes consent from all necessary persons i.e. participants and parents.

a) No
b) No
c) Not applicable
d) All participants will be over 18 and will complete an informed consent form and PARQ.

20. Risks and benefits of research/ activity

a) Are there any potential risks or adverse effects (e.g. injury, pain, discomfort, distress, changes to lifestyle) associated with this study? If so please provide details, including information on how these will be minimised.
b) Please explain where the risks / effects may arise from (and why), so that it is clear why the risks / effects will be difficult to completely eliminate or minimise.
c) Does the study involve any invasive procedures? If so, please confirm that the researchers or collaborators have appropriate training and are competent to deliver these procedures. Please note that invasive procedures also include the use of deceptive procedures in order to obtain information.
d) Will individual/group interviews/questionnaires include anything that may be sensitive or upsetting? If so, please clarify why this information is necessary (and if applicable, any prior use of the questionnaire/interview).
e) Please describe how you would deal with any adverse reactions participants might experience. Discuss any adverse reaction that might occur and the actions that will be taken in response by you, your supervisor or some third party (explain why a third party is being used for this purpose).
f) Are there any benefits to the participant or for the organisation taking part in the research (e.g. gain knowledge of their fitness)?

a) There no evidence to suggest that occlusion training poses any risks to healthy subjects who have no history of cardiovascular disease, hypertension or blood clotting problems. Notwithstanding this all of the restriction pressures used in this study will be individualised and carefully monitored throughout the exercise procedures.

b) In a survey of 12,642 participants who have partaken in some kind of occlusion training the most frequently occurring side-effects were sub-cutaneous bruising around the pressure cuff (13.1%) and light headedness (0.3%) (Klatsky et al., 2000). The bruising reported in this survey was from using much thinner occlusion cuffs than those used by Dr. Patterson. The wider cuffs used by Dr. Patterson allow for uniform pressure to be dispersed over a greater contact area and have not resulted in any adverse effects from over 60 people training with them. Dr. Patterson completed his PhD in this area, has published research in this area and has studied blood flow

restriction exercise on subjects of various ages for 4-5 years with no adverse effects.

c) The only collection of bodily fluids will be that of blood for blood lactate analysis. This will be performed by a trained lab technician.

d) There will be no sensitive or upsetting questions in the recruitment questionnaires.

e) Any adverse reaction or incident will be dealt with immediately by a properly qualified first aider and/or the lab technician

f) Subjects will discover their 1RM score and their own responses to squatting under different occlusion pressures.

21. Confidentiality, privacy and data protection

a) What steps will be taken to ensure participant's confidentiality?
- Describe how data, particularly personal information, will be stored.
- Consider how you will identify participants who request their data be withdrawn, such that you can still maintain the confidentiality of theirs and others data.

b) *Describe how you manage data using a data a management plan.*
- *You should show how you plan to store the data securely and select the data that will be made publically available once the project has ended.*
- *You should also show how you will take account of the relevant legislation including that relating data protection, freedom of information and intellectual property.*

c) Who will have access to the data? Please identify all persons who will have access to the data (normally yourself and your supervisor).

d) Will the data results include information which may identify people or places?
- Explain what information will be identifiable.
- Whether the persons or places (e.g. organisations) are aware of this.
- Consent forms should state what information will be identifiable and any likely outputs which will use the information e.g. dissertations, theses and any future publications/presentations.

a) All data will be kept anonymous from all subjects and stored on a computer which is password protected. Data will be held in confidence and not discussed between any parties other than Dr. Stephen Patterson and Tristan Baker.

b) Please see above.

c) Only the collaborators (Dr. Stephen Patterson and Tristan Baker) will have access to the data.

d) The data results will not include any information which can identify any individuals or places.

22. Feedback to participants

Please give details of how feedback will be given to participants:

• As a minimum, it would normally be expected for feedback to be offered to participants in an acceptable to format, e.g. a summary of findings appropriate written. • Please state whether you intend to provide feedback to any other individual(s) or organisation(s) and what form this would take.
Feedback will be provided to the individuals participating in the study who ask to see their results. This will be done under the supervision of either Tristan Baker or Stephen Patterson.

The proposer recognises their responsibility in carrying out the project in accordance with the University's Ethical Guidelines and will ensure that any person(s) assisting in the research/ teaching are also bound by these. The Ethics Sub-Committee must be notified of, and approve, any deviation from the information provided on this form.

Signature of Proposer(s) Tristan Baker	Date: 9/2/16
Signature of Supervisor (for student research projects) 	Date: 12/2/16

Approval Sheet

Name of applicant: Tristan Baker

Name of supervisor: Stephen Patterson

Programme of study: Strength and Conditioning Masters

Title of project: **How does blood flow restriction exercise and high load resistance training effect muscle activation patterns and oxygenation in endurance and weightlifting athletes?**

Supervisors, please complete section 1 or 2. If approved at level 1, please forward a copy of this Approval Sheet to the School Ethics Representative for their records.

SECTION 1

Approved at Level 1

Signature of supervisor (for student applications).....

Date.....

SECTION 2

Refer to School Ethics Representative for consideration at Level 2 or Level 3

Signature of supervisor..... .....

Date.....12/2/16.....

SECTION 3

To be completed by School Ethics Representative

Approved at Level 2

Signature of School Ethics Representative. J. Hill..... .....

Date.....15/2/16.....

SECTION 4

To be completed by School Ethics Representative. Level 3 consideration required byt the Ethics Sub-Committee (including all staff research involving human participants)

Signature of School Ethics Representative.....

Date.....

Level 3 approval – confirmation will be via correspondence from the Ethics Sub-Committee

Appendix B

The Research Project

The effect of blood flow restriction exercise and high load resistance training on internal knee joint loads, muscle activation patterns and muscle oxygenation during a closed kinetic chain exercise

Purpose and value of the study

The aims of this investigation are to identify the effect of blood flow restriction (BFR) exercise and high load resistance training (HLRT) during the half squat exercise on knee joint loads, muscle activation patterns and muscle oxygenation. Importantly, knee stability is paramount in improving a patient's knee rehabilitation, minimizing injury potential and a necessary target to an athlete's performance and training. Whilst the adaptation elicited on the muscular system of the lower limb with HLRT and BFR exercise is the preferred methods to induce increases in muscle mass, the joint loads of doing such training interventions is often overlooked. This study will aim to quantify the knee joint force with the measurement of muscle activation of six lower limb muscles. This will determine the effect of multiple repetitions and sets of BFR and HLRT exercise on muscle activation and estimated joint forces. Alongside this, the oxygen saturation of the working muscles will be observed in order to establish how individuals of different muscle-fibre phenotypes respond to BFR conditions. This will guide practitioners as to whether the loads lifted during traditional HLRT and BFR protocols are similar throughout the protocol or do knee joint loads increase and/or muscle activation strategies make alterations. Practitioners will also be guided as to the best practical use for BFR exercise with endurance athletes or weightlifting athletes.

Invitation to participate

You are invited you to participate in a research study examining the effect of BFR and HLRT on knee joint loads and muscle activation and oxygenation

Who is organising the research?

The research is being organised by William Page, Tristan Baker and Dr Stephen Patterson.

What will happen to the results of the study?

The results of the research will be available from William Page and Tristan Baker within 60 days of all data being collected. You will receive your own individual results. Ultimately your data may be published in an international journal. All participation will be anonymous from any publication.

Source of funding for the research

There are no external sources of funding for this study.

Contact for further information:

William Page: William.page@stmarys.ac.uk (07712259307)

Tristan Baker: 135186@live.stmarys.ac.uk (07517209244)

Dr Stephen Patterson: Stephen.Patterson@stmarys.ac.uk (02082402357)

Why you have been invited to take part?

You have been chosen because you are a healthy male, who regularly undertakes endurance/strength training and are over the age of 18. We plan to carry out this study with 10 people like you.

Do I have to take part?

It is up to you to decide whether or not to take part. If you decide to take part you will be given this information sheet to keep and be asked to sign a consent form. You will be given copies of these.

Can I withdraw from the study?

If you decide to take part you are still free to withdraw at any time, without giving a reason and without any penalty. You can withdraw by completing the withdrawal form at the bottom of the consent form and handing it back to a member of the research team.

What will happen if you agree to take part?

There will be four separate study days. You will be asked to refrain from caffeine and alcohol for 12 hours prior to each study. We will also ask you to avoid any strenuous exercise for 24 hours prior to the study. You will be asked to come to the St Marys University College Biomechanics Lab, where the study will take place. You will then be asked to sign a consent form and health screening questionnaire.

Day 1 – Familiarisation Trial One

On the day, you will arrive in the laboratory and perform your first familiarisation trial. Familiarisation One will include the collection of limb occlusion pressure and familiarity with the standardised warm-up, squat set-up and tempo and 1RM back squat to 100° of knee flexion. This trial will take approximately 1 hour and must be completed at least 2 days before Trial Two.

Day 2 – Familiarisation Trial Two

Familiarisation Two will include the completion of the BFR protocol. This trial will take approximately 1 hour and must be completed at least 5 days before Trial Three. If this protocol is too challenging and you are unable to complete the protocol, this will be your last session.

Day 3 and 4 – Experimental Trial

On the experimental days you will arrive at the laboratory and you will either receive BFR exercise or HLRT. This will be conducted with sticky markers on your skin and probes to record your activation and oxygen saturation of the muscles of the lower limbs. Skin preparation will be conducted prior to this to ensure data collection in correct and accurate. In the BFR trail, the pressure cuff will be placed around the proximal thigh. Low-load exercise at 30% of 1RM with a standard scheme of 30–15–15–15 repetitions and 45second interset recovery will be performed. These cuffs will be maintained throughout the protocol. This low-load resistance exercise combined with BFR has been suggested to produce a substantial increase in muscle mass and strength in both single- and multi-joint exercises. The high load protocol will consist of four sets of seven repetitions at 80% 1RM with a 180second interest recovery. Similar protocols have produced substantial increases in muscle hypertrophy and strength in both clinical investigations and training situations. Completion of these trials will take approximately 70 minutes each.

Are there any risks or side effects?

Blocking the blood supply to the leg will not cause any damage. Similar studies on numerous individuals, in both healthy volunteers and elderly individuals have seen no side effect. There may be some discomfort caused by the blood pressure cuff when it is inflated but this has been well tolerated by healthy and elderly volunteers. In addition, when the cuff is deflated, you might feel “pins and needles” in your toes, but this resolves in a few minutes. Muscle soreness, stiffness and tightness may be experienced afterwards but this will decrease 48-72 hours post exercise.

Agreement to participate in this research should not compromise your legal rights if something goes wrong.

Research can carry unforeseen risks and we want you to be informed of your rights in the unlikely event that any harm should occur as a result of taking part in this study. Every care will be taken to ensure that your well-being and safety are not compromised during the course of the study. St Marys University, Twickenham also has insurance arrangements in place in the unlikely event that something does go wrong and you are harmed as a result of taking part in the research study.

Are there any special precautions you must take before, during or after taking part in the study?

You will be asked to refrain from caffeine and alcohol for 12 hours prior to each study. We will also ask you to avoid any strenuous exercise 24 hours prior to commencing and the duration of the study.

What will happen to any information/data/samples that are collected from you?

Only named researchers and a representative of the Research Ethics Committee will have access to the data collected during the study. However, your identity will not be revealed. All information which is collected about you during the course of the research will be strictly confidential and kept on a password protected computer. We will keep a record that you have taken part in the study but will not keep any other personal information about you. Professional standards of confidentiality will be adhered to and the handling, processing,

storage and destruction of data will be conducted in accordance with the Data Protection Act (1998).

Are there any benefits from taking part?

There will be no direct benefits from the study. However the information we get from this study may help us understand whether knee joint loads increase with BFR and HLRT and the extent to which BFR exercise effects the oxygenation of the working muscles.

How much time will I need to give up taking part in the project?

The total time commitment will be approximately 4 hours and 20minutes over 4 days.

Contact details of the university

St Mary's University, Waldegrave Road, Strawberry Hill, Twickenham, TW1 4SX

Will Page

Tel: 020 8240 4000 – Ext 4099

Email: - william.page@stmarys.ac.uk

Tristan Baker

Tel: 07517 209244

Email: 135186@live.stmarys.ac.uk

YOU WILL BE GIVEN A COPY OF THIS FORM TO KEEP TOGETHER WITH A COPY OF YOUR CONSENT FORM

Appendix C

St Mary's University Twickenham London

NAME OF PARTICIPANT: _____

Title of the project: **How does blood flow restriction exercise and high load resistance training effect muscle activation patterns and oxygenation in endurance and weightlifting athletes?**

Main investigator and contact details: Mr Tristan Baker

Email: 135186@live.stmarys.ac.uk

Mobile: 07517 209244

1. I agree to take part in the above research. I have read the Participant Information Sheet which is attached to this form. I understand what my role will be in this research, and all my questions have been answered to my satisfaction.

2. I understand that I am free to withdraw from the research at any time, for any reason and without prejudice.

3. I have been informed that the confidentiality of the information I provide will be safeguarded.

4. I am free to ask any questions at any time before and during the study.

5. I have been provided with a copy of this form and the Participant Information Sheet.

Data Protection: I agree to the University College processing personal data which I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Name of participant (print)……Signed……..Date……

Name of witness (print)……Signed……..Date……

If you wish to withdraw from the research, please complete the form below and return to the main investigator named above.

Title of the project: The effect of different application timings of Ischemic Preconditioning (IPC) on cycling time trial performance.

I WISH TO WITHDRAW FROM THIS STUDY

Name: _____

Signed: _____ Date: _____